Comment on “Entry Distribution, Fission Barrier, and Formation Mechanism of $^{254}_{102}$No ”

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A recent paper [1] has reported the observation of the rotational band of ^{254}No for spins up to I=20, showing that the compound nucleus was formed and survived fission decay at angular momenta $I \geq 20$. This finding may appear surprising, given the known instability toward fission of these nuclei and the expected decrease in the fission barrier due to angular momentum. The question behind the surprise is why angular momentum, usually so effective in decreasing the fission barrier in lighter nuclei, appears here to be ineffective. The explanation of this puzzle is not only interesting for this case, but is also even more relevant for the resilience to angular momentum of superheavy nuclei.

Clearly, there is the simple fact that the natural scale for I^2 is $A^{5/3}$, which makes the observed dimensionless angular momentum rather small at A=254 compared to what it would be for instance at $A \approx 200$.

However, there is a more important reason for the “survival” of the fission barrier. Namely, the very small difference in deformation (and thus in the moment of inertia) between the saddle point and the ground state.

To show the leading effects of angular momentum on the barrier height, we use perturbation theory to calculate the energy

$$E\left(\vec{\epsilon}\right) = E_0\left(\vec{\epsilon}\right) + \frac{I(I+1)\hbar^2}{2\mathcal{J}(\vec{\epsilon})} \tag{1}$$

where $\vec{\epsilon}$ is a generalized deformation vector, $E_0(\vec{\epsilon})$ and $\mathcal{J}(\vec{\epsilon})$ are the potential energy surface and moment of inertia at $I = 0$. As shown in Fig. 1, the decrease of the barrier height $\Delta B(I)$ due to angular momentum is

$$\Delta B = \frac{\hbar^2}{2}\left(\frac{1}{\mathcal{J}_g} - \frac{1}{\mathcal{J}_s}\right) I(I+1) \tag{2}$$

where $\mathcal{J}_g$ and $\mathcal{J}_s$ are the moments of inertia of the ground and saddle deformations. This decrease depends strictly on the values of the two moments of inertia at I=0 irrespective of their origin (liquid drop, shell effects, pairing, etc.). Higher order effects, such as changes in the ground and saddle deformation, and shell and pairing effects are occurring at higher angular momenta.

In typical lighter nuclei, the saddle point is controlled by the liquid drop contributions and is found to be at large deformations. Therefore, $\mathcal{J}_g << \mathcal{J}_s$ and $\Delta B \approx \hbar^2 I(I+1)/2\mathcal{J}_g$. This produces the large effect of angular momentum on the fission barrier for lighter systems.

However, in trans-Fermium nuclei, the ground state is already deformed at the values of ϵ typical of all actinides.

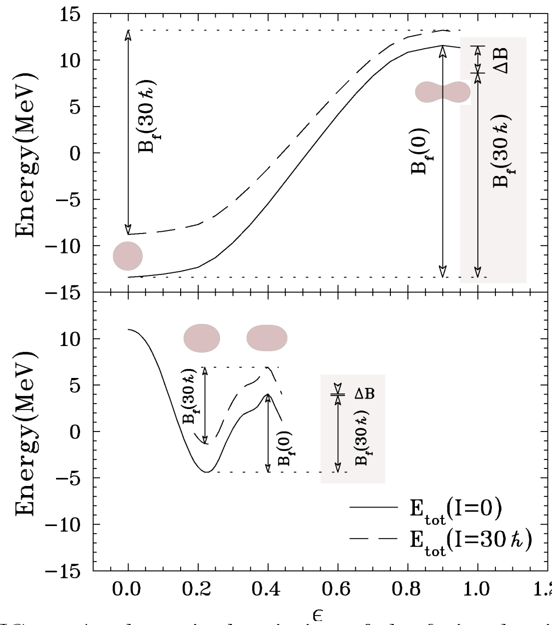

FIG. 1. A schematic description of the fission barrier for a light nucleus (A = 208, top panel) and a heavy nucleus (A = 254,bottom panel). The solid line represents the total energy as a function of deformation when I = 0, while the dashed line is calculated for $I = 30\hbar$. The shapes represent the ground state and saddle configurations.

The saddle occurs at a deformation only slightly greater, corresponding to the anti-shell immediately following the deformed minimum. Thus, $\mathcal{J}_g \sim \mathcal{J}_s$ and we can expand Eq. (2) for small values of $\Delta\mathcal{J} = \mathcal{J}_s - \mathcal{J}_g$, obtaining

$$\Delta B \approx \frac{\hbar^2 I(I+1)}{2\mathcal{J}_g}\frac{\Delta\mathcal{J}}{\mathcal{J}_s} = E^{gs}_{rot}\frac{\Delta\mathcal{J}}{\mathcal{J}_s}. \tag{3}$$

Consequently, the decrease in barrier height is equal to the ground state rotational energy (E^{gs}_{rot}) times the fractional change in the moment of inertia. For I=20, the rotational energy $E^{gs}_{rot} \approx$1.5 MeV and ΔB is a small fraction of it (< 0.1 MeV). These features are pictorially shown in Fig. 1

There is little doubt that this is the cause of the resiliency of the No barrier to angular momentum. The same arguments speak for a similar resilience in superheavy nuclei. Thus, we expect that we can safely graze in the pastures of the superheavy island of stability, without fear of (moderate) angular momentum values.

[1] P. Reiter *et al.*, Phys. Rev. Lett. **84**, 3542 (2000).